WINTER TEMPERATURE STRUCTURE OF THE GREAT LAKES

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FOREWORD

This report is the first annual report of work performed under the National Science Foundation, Atmospheric Sciences Section Research Grant GA-524. The project is titled "Winter Temperature Structure of the Great Lakes." The total project period is 1 June 1966 through 31 May 1968.

The aims of the project are to test the potentials of a proposed ice-prediction technique, and to investigate the winter heat storage of the Great Lakes. This program is the continuation of an earlier NSF, Atmospheric Sciences Section, Research Grant GP-2411 titled "Growth of Ice on Lake Michigan." The final report of the previous project was published in 1966 as Special Report No. 26 of the Great Lakes Research Division, of the University of Michigan.

ICE PREDICTION STUDIES

Early-winter BT casts were taken for the second consecutive year by USCGC WOODBINE in Lake Michigan to provide the water temperature data for ice cover prediction. From the observations of 3 December, 9 December, and supported by additional information from 18 December, a prediction of a moderately heavy amount of ice on Lake Michigan was made for the 1966-67 winter.

The early winter weather, as described in "Climatological Data" published by the U.S. Weather Bureau, was extremely unsettled in December 1966 and January 1967. Record low temperatures were recorded on 3 December, with record highs of 64°F to 66°F on 8 December. On 24 January, record high temperatures up to 66°F were again recorded. February and March were very cold months. Record snowfalls occurred in January and February 1967. The warm December and January temperatures delayed the formation of ice, but the cold February and March caused persistence of the ice well into the spring of the year.

In spite of the variability of the season's weather, and although no systematic program of ice observations had been carried out for Lake Michigan, conversations with a few of the ship captains who were operating on Lake Michigan during the winter indicated that the prediction was not too far off. The ice condition would have been better described as moderate, than as moderately heavy.

There is a basic problem in attempting to verify predictions of ice formation on the Great Lakes. There is rarely full ice coverage of the lake surface, and whenever there is only partial coverage, any ice which is formed is acted upon by the combined effects of wind and waves, and generally forms windrows along the southeast shore. Therefore, the amount of

ice that is formed, and its consequent effect upon navigation, cannot be expressed as a simple percentage of the lake surface covered by the ice.

The model for ice prediction was based on weekly average temperatures measured at deep-water locations with United States Public Health Service buoys during the winters of 1962-63 and 1963-64. No winter temperatures were available for the 1964-65 season. As was reported at a meeting of the U.S. Coast Guard, U.S. Lake Survey, and University of Michigan at U.S. Lake Survey offices in Detroit on 19 January 1966, the December 1965 water temperatures from the WOODBINE BT's indicated a light ice year. This prediction verified.

During the summer of 1966, there was relatively light storm activity, and the surface of the lake became quite warm, but in a thin layer with a shallow thermocline. The fall storms mixed the waters of the lake with the result of very low water temperatures in early December, thus creating conditions for easy formation of ice. The actual rate of ice formation is defined by the early winter freezing exposure, and therefore the warm spells in December and January inhibited ice formation until well after the winter season had begun.

During the first week in December 1962, the average temperature at PHS Station 18 (approximately 20 miles east of Milwaukee) was 5.9°C. 1962-63 was a record year for ice cover. During the first week in December 1963, the average temperature at Station 18 was 8.8°C. 1963-64 was a very light ice year. Temperatures from WOODBINE BT's in the southern end of Lake Michigan ranged from 7.3 to 9.4°C from 3 December to 9 December 1965. 1965-66 was a light ice year. Temperatures from WOODBINE BT's ranged from 4.2 to 8.2°C from 3 December to 9 December 1966. 1966-67 was a moderate ice year. (No calibrated water temperature measurements were made for the 1964-65 season.)

The model for the ice prediction was based on a one-week average of continuous records from recording thermographs. The BT measurements from the WOODBINE consist of approximately 5 BT casts over the southern basin of the lake. Therefore, it has been necessary to compare point measurements from five locations with a continuous recording at a single location. However, it does appear that the BT soundings do present a useful prediction index.

Furthermore, examination of the BT records shows that the water column is nearly isothermal and that surface temperatures alone may provide equally good information.

A thermistor temperature indicator was installed on the WOODBINE during the BT run in 1966. This indicator is a carefully calibrated temperature bridge, with the sensing thermistor in the main sea chest of the WOODBINE. The thermistor became defective during the winter, but the unit will be replaced and recalibrated this summer. The temperature bridge will be recalibrated again in the fall for use during a BT run in early December of 1967.

A preliminary request has been made to the U.S. Coast Guard for permission to continue the BT operation from the WOODBINE during the early winter of 1967. It is expected that this permission shall be granted. It is anticipated that one more year of BT data will demonstrate conclusively that the temperature-depth profile is isothermal during the first week of December, and that only accurate surface temperatures during this period will be necessary for ice prediction.

THERMISTOR TEMPERATURE INDICATOR

Figure 1 is a schematic diagram of the thermistor temperature indicator developed for installation aboard the USCGC WOODBINE. The temperature bridge is designed for use with type 32A84 or T32A11 thermistors. The bridge circuit is designed with sufficient adjustments so that the temperature scale can be made linear (within ± 0.1°C) and with two temperature ranges. The temperature scale can be switched to 0° to 25°C, or to 0° to 12.5°C full scale. The high scale is used during summer operations, and the low scale is used for winter measurements.

Temperature-resistance calibration curves are made for each thermistor to be used with the bridge circuit. The thermistors are mounted in a monel pipe plug that is screwed into the sea chest of the main suction line of the ship. The thermistors are calibrated after being potted in the pipe plug.

After calibration, the individual thermistor curves are used for calibration of the indicator bridge. The bridge calibration is carried out by using a resistance substitution box in place of the thermistor. The ZERO potentiometer and the full-scale ADJUST are used to define the end-points of the output current-temperature curve (meter scale). The METER potentiometer is used to conpensate non-linearities on the scale. All three of these adjustments are interdependent. During the process of calibration, the ZERO and METER potentiometers are locked at their optimum settings. The ADJUST potentiometer is used both when the temperature scale is changed and to compensate for change in battery voltage. SW3 is a momentary-contact switch that substitutes an internal resistance in place of the thermistor. During field operations, the scale switch SW2 is set for the desired meter scale, and SW3 is closed to check the bridge calibration.

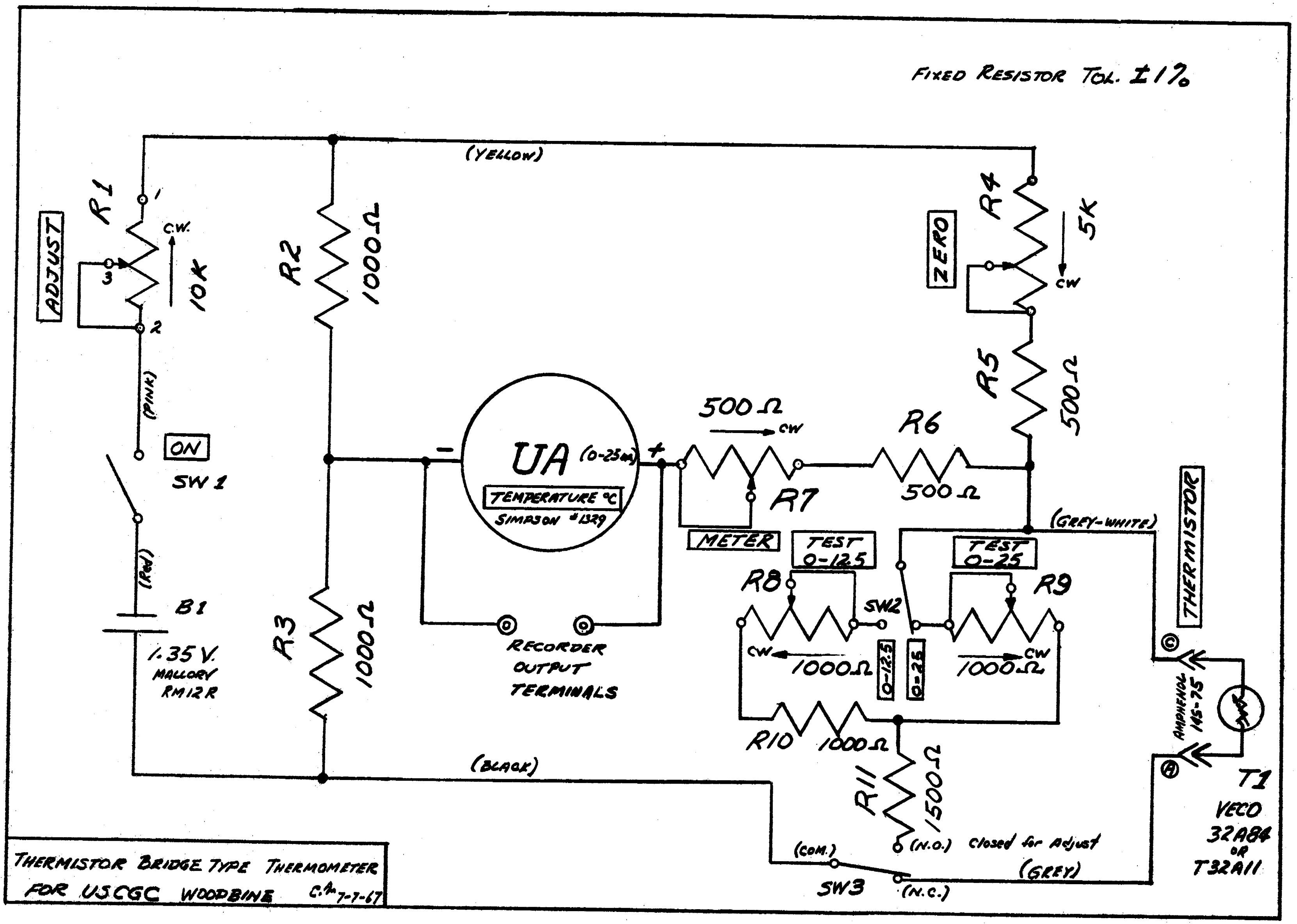

FIG. 1. Schematic diagram of thermistor bridge.

While SW3 is closed, the ADJUST potentiometer, R1, is varied so that the meter points to a red line previously scribed on the meter scale. The TEST potentiometers, R8 and R9, are adjusted so that the calibration adjustment is made at the same red line for both meter scales. Output jacks provide a linear output to a high input impedance recording potentiometer.

SOLAR RADIATION MEASUREMENTS

Due to technical problems of construction and calibration of integrating solar radiometers, these instruments were not completed in time for installation around the basin of the lake during the 1966-67 winter season, as originally proposed. These instruments have been constructed according to the design of Federer and Tanner (1965), and have been tested on campus during the latter part of the winter. Minor changes will be made, and the instruments will be placed in operation around the lake basin in time for the winter season of 1967-68.

Figure 2 is a schematic diagram of the integrating radiometers. The electrochemical integrator consists of a capillary tube containing a mercury column that is separated into portions by a "gap" containing a transparent electrolyte. Current generated by the photovoltaic cells causes the mercury to be plated from one side of the gap to the other, thus causing the gap to move down the capillary tube. The surface of the voltage cell is masked to scale the integrator output. The units tested on campus were adjusted so that full-scale transport of the gap (one inch of movement) would correspond to approximately 400 langleys of input radiation.

Figures 3 through 7 show calibration curves obtained from five integrating radiometers as a result of last season's trial operation. The initial gap position was measured to the nearest 0.001 inch with a hand-held microscope. At the end of a 24-hour period, the final position of the gap was similarly measured. The integrator was reset to zero during the second day with a battery source operated by a timing device. A second integrator is used with each radiometer to obtain continuous records while the first is being reset.

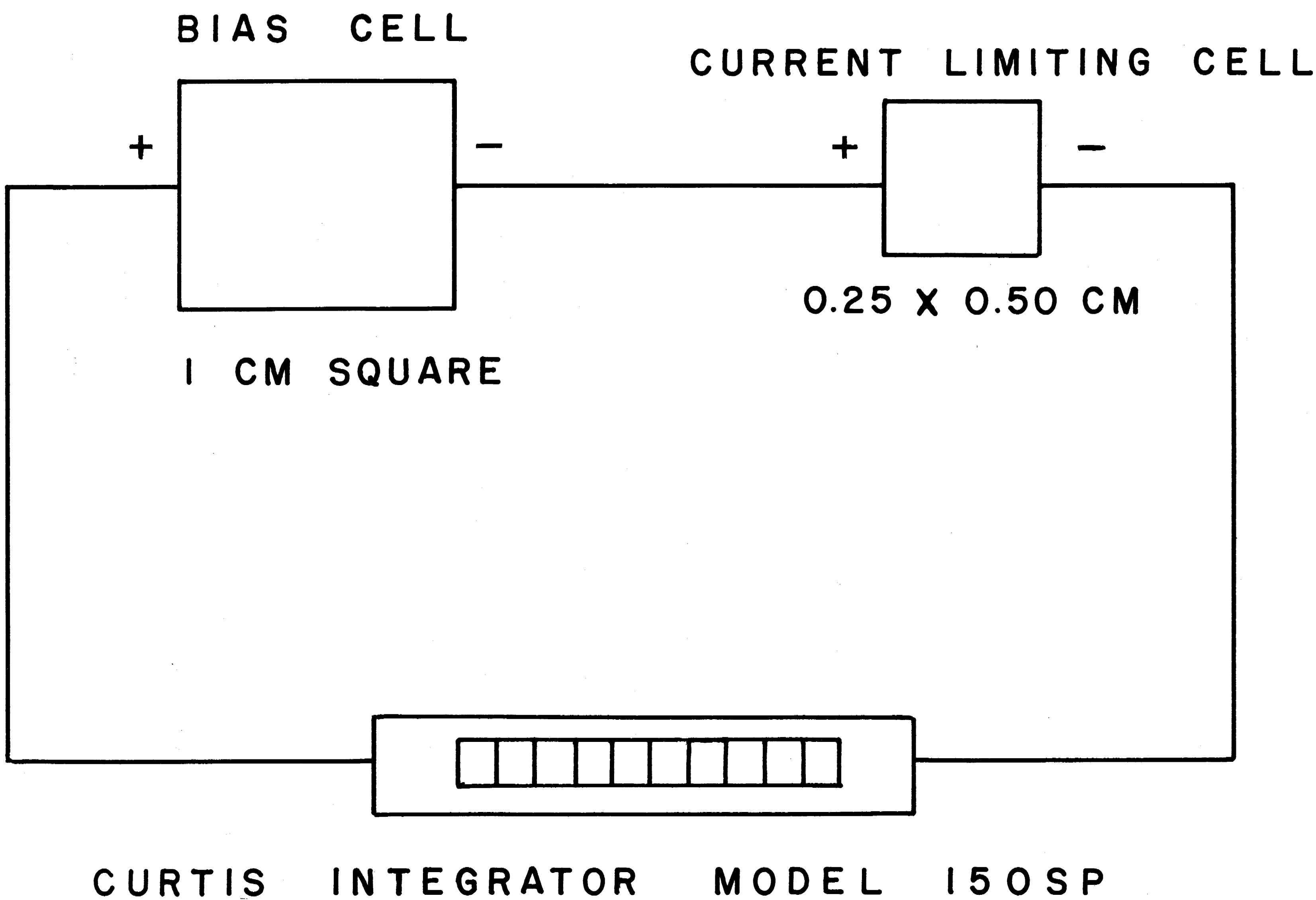

FIG. 2. Schematic diagram of an integrating radiometer.

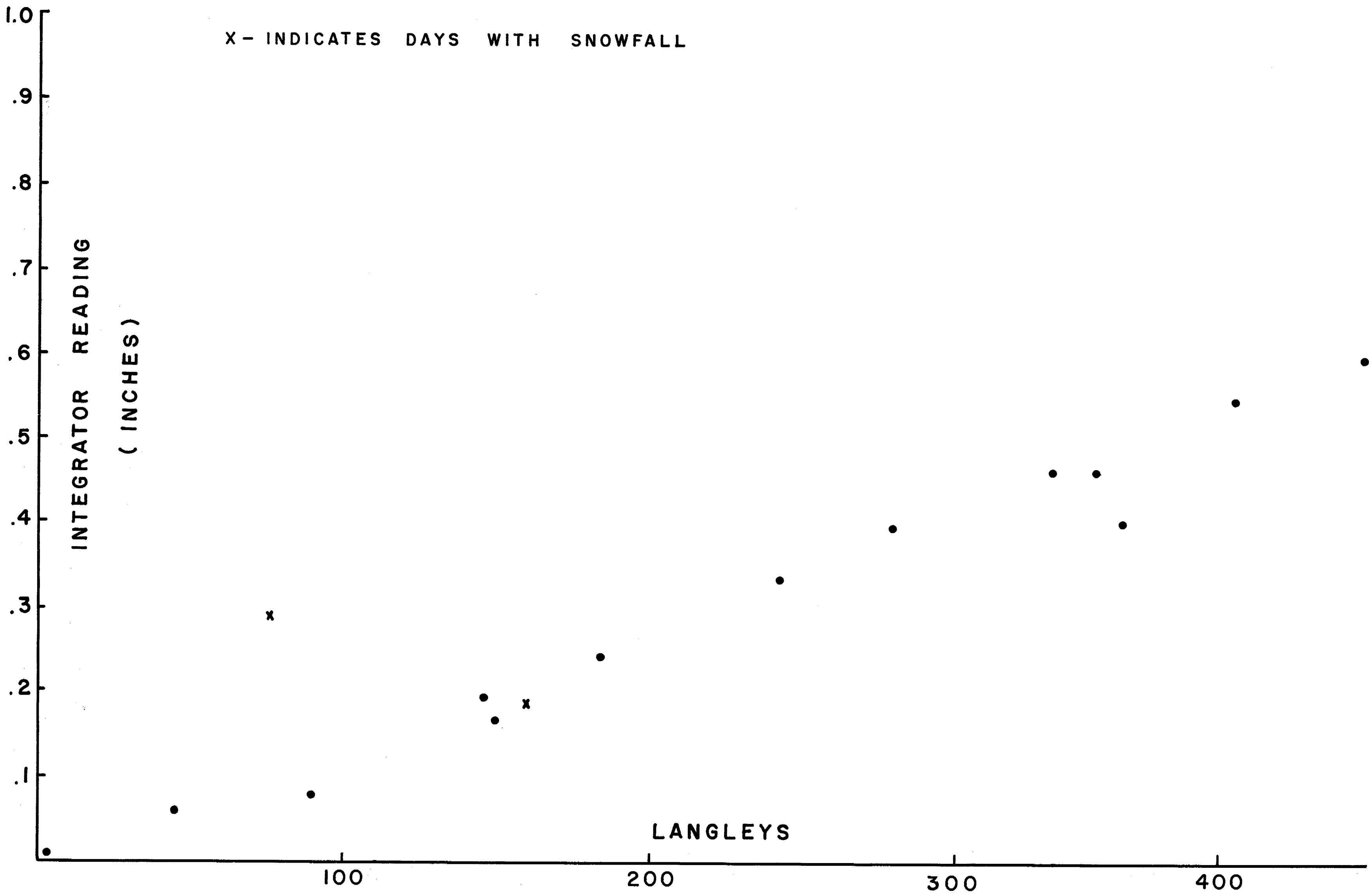

FIG. 3. Calibration curve for integrating radiometer No. 1.

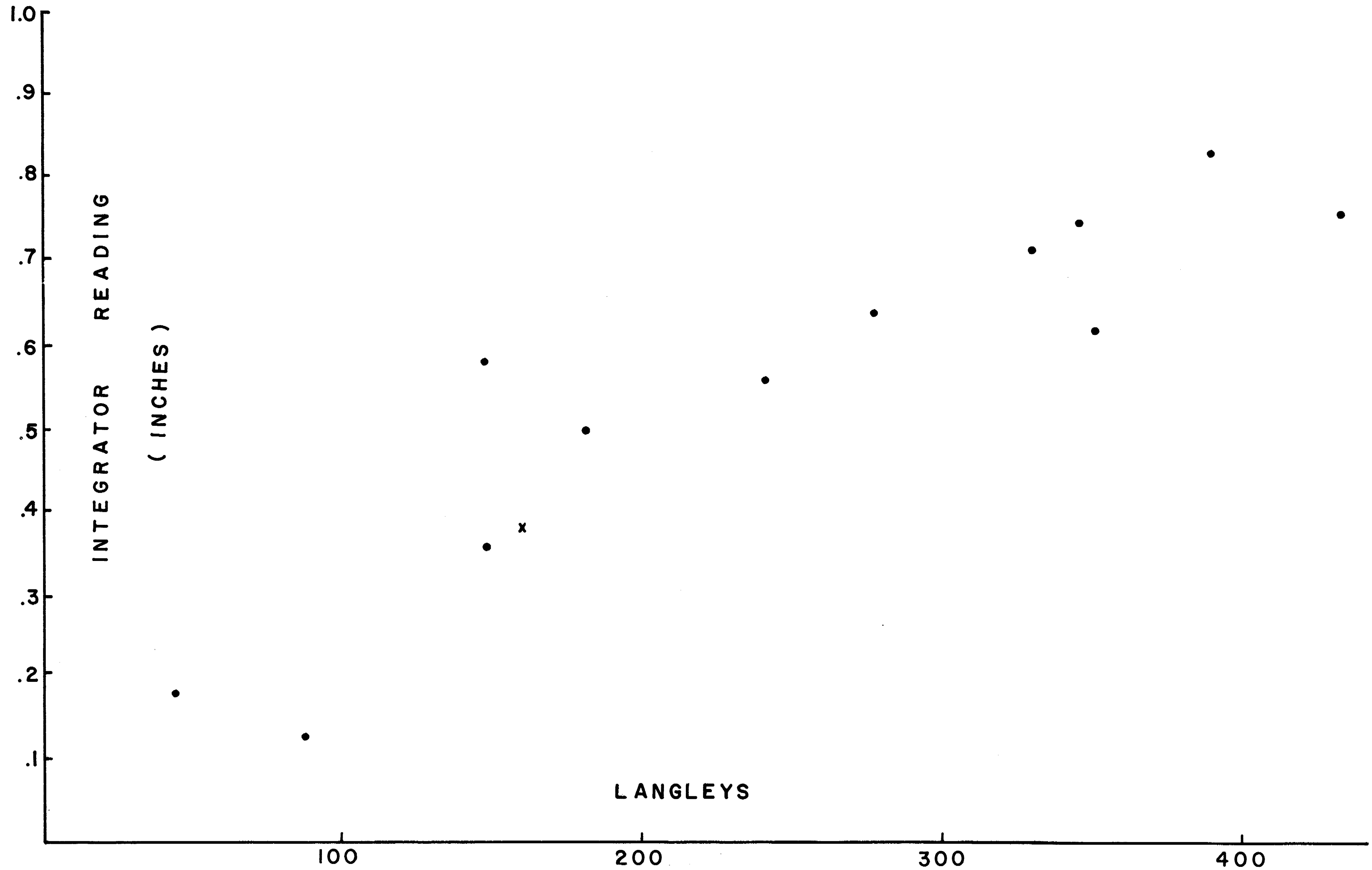

FIG. 4. Calibration curve for integrating radiometer No. 2.

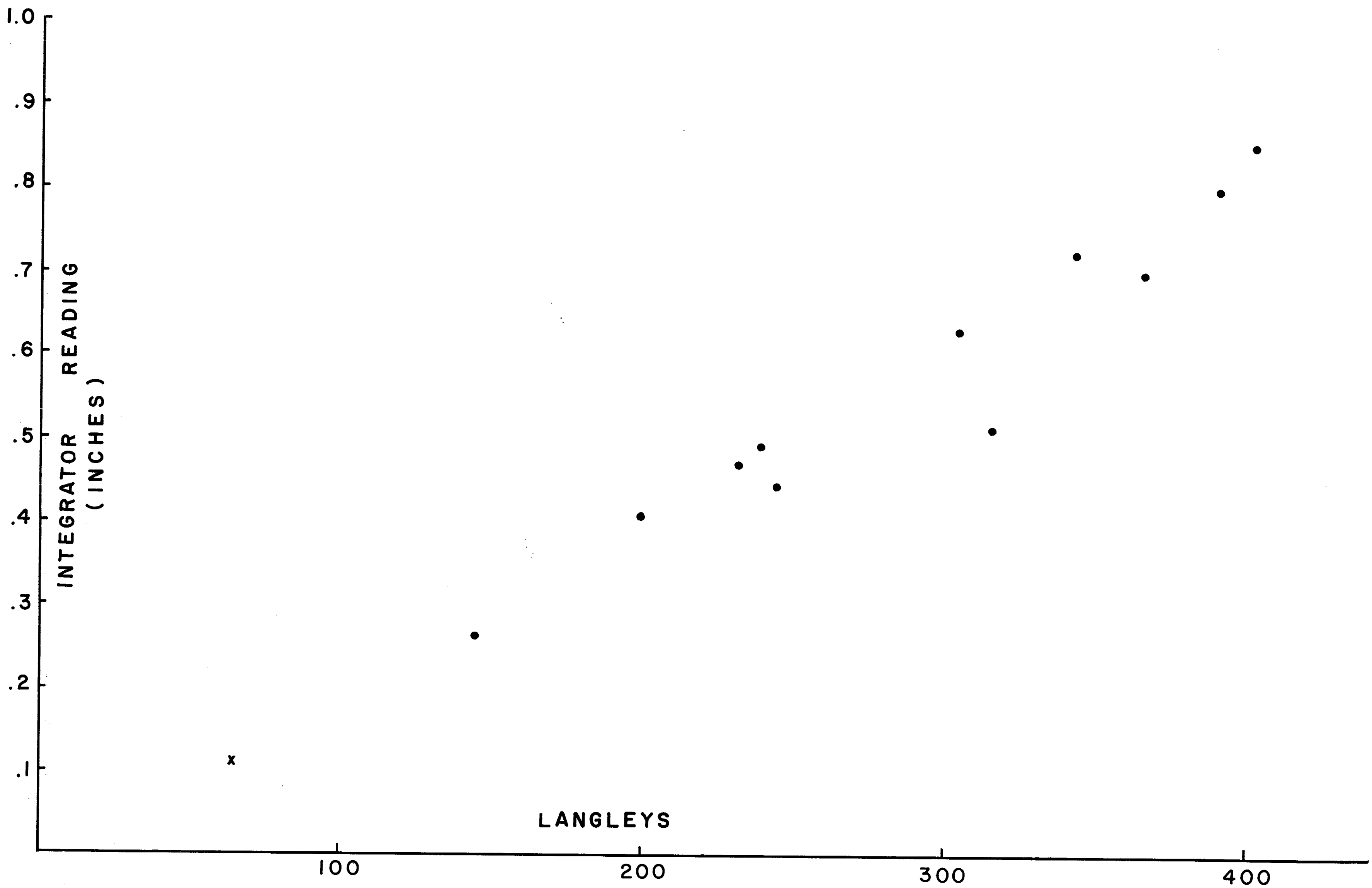

FIG. 5. Calibration curve for integrating radiometer No. 3.

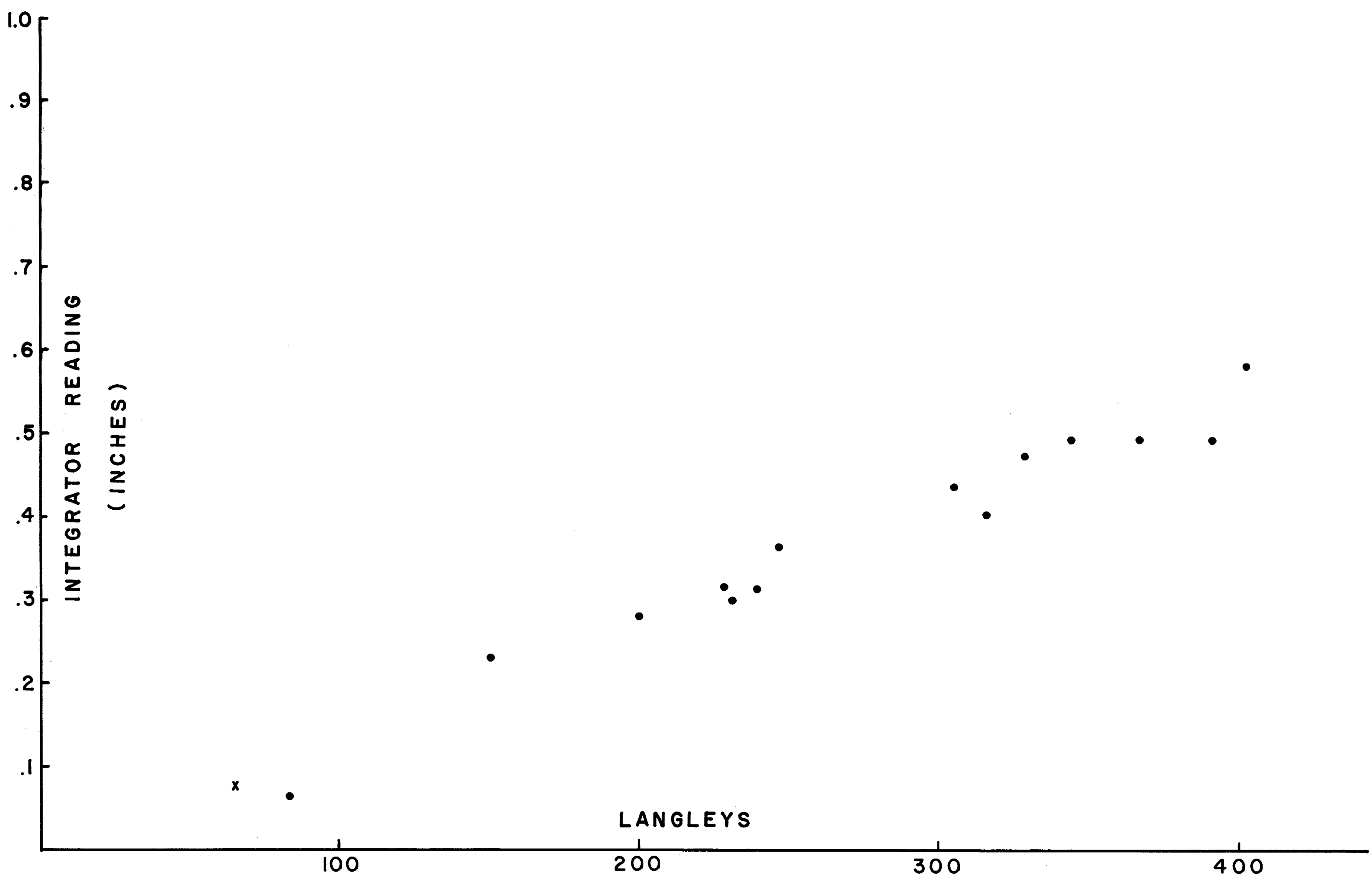

FIG. 6. Calibration curve for integrating radiometer No. 4.

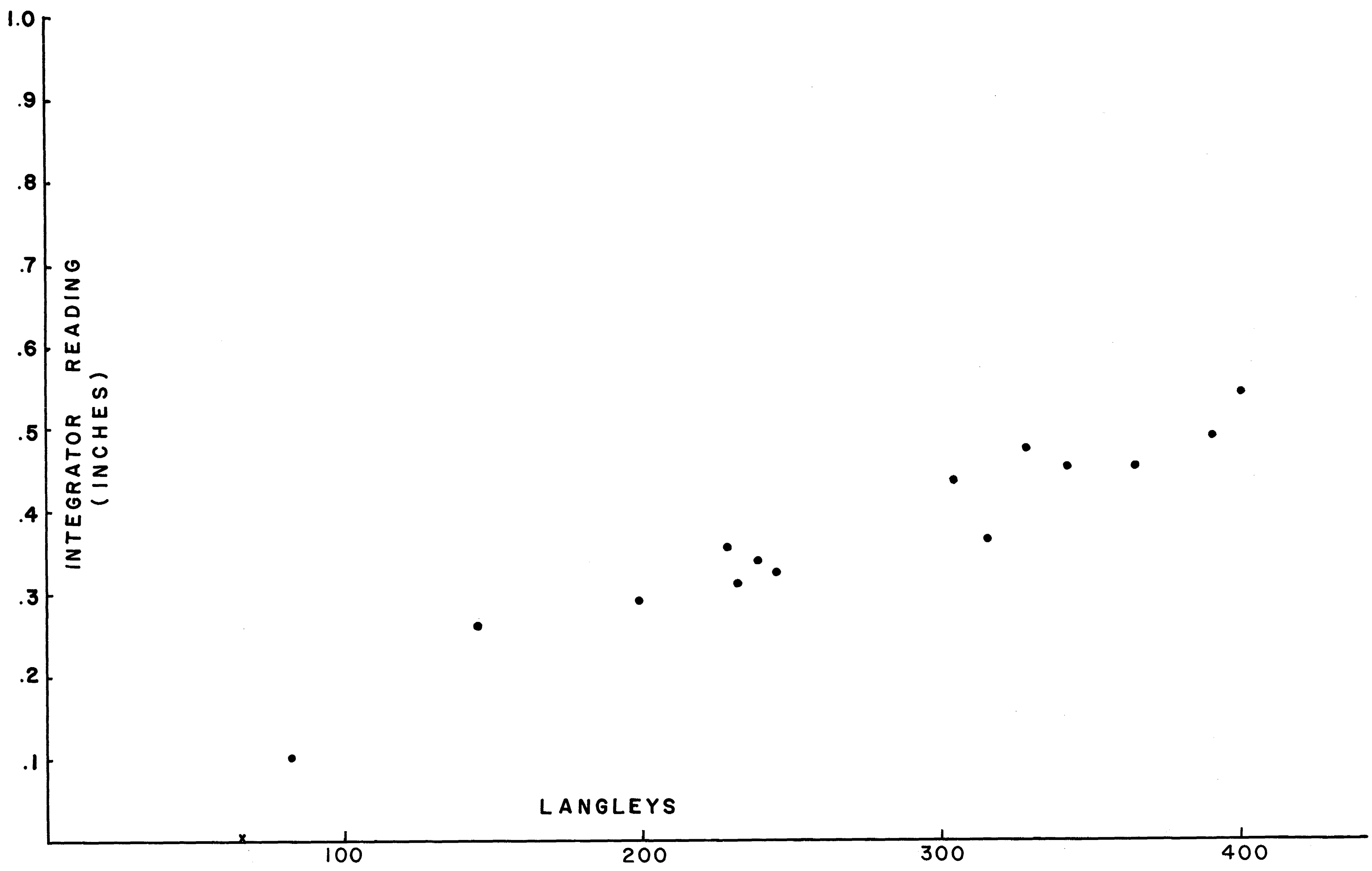

FIG. 7. Calibration curve for integrating radiometer No. 5.

The integrating radiometers were calibrated by comparison with data from manually integrated (using a polar planimiter) analog traces from an Eppley Pyrheliometer. Recognizing that a certain amount of the scatter of the points of the calibration curve are due to errors in manually integrating Eppley records from cloudy days, it is estimated that the integrating radiometers yield values that are within 10% of the true values for incoming solar radiation.

The component cost for these integrating radiometers is approximately $50, including the integrators, solar cells, reset timing device, and hand microscope for reading.

WINTER AIR MASS MODIFICATION

In the early report (Heap and Noble 1966) it was shown that the cumulative air temperature increase (heat gained by the air mass crossing the lake) between Milwaukee and Muskegon was approximately the same for both the 1962-63 and the 1963-64 winter seasons.

The operational definition of the winter season was from the first week in October until the onset of spring warming, which was about the middle of April. The freezing exposure was computed by adding the cumulative centigrade degree days from the first of October. The cumulative centigrade degree days are a direct measure of the freezing exposure, since 0°C is the freezing point. The approximate characteristics of the curves, an example of which is shown in Figure 8, shows that the average air temperature is still above freezing from the first of October into the first week of December. The temperatures used for the computation of the freezing exposure were the average between the maximum and minimum daily temperatures as given by the climatological data. The seasonal freezing exposure, or equivalently the severity of the winter, is indicated by the decrease in the cumulative degree days from its maximum in the first of December to its minimum in the first of March. The fall maximum value depends upon the arbitrary selection of the first of October as the onset of winter. The freezing exposure which is measured as an accumulation of negative degree days is therefore given by the difference between the maximum and minimum values of the seasonal curve.

Figure 8, which shows the cumulative centigrade degree days for Milwaukee and Muskegon for the years 1962-63 and 1963-64, is representative of two wide extremes in severity of the winter seasons. The fall maximum of degree days in Milwaukee in 1962 was approximately 500 degree days. The

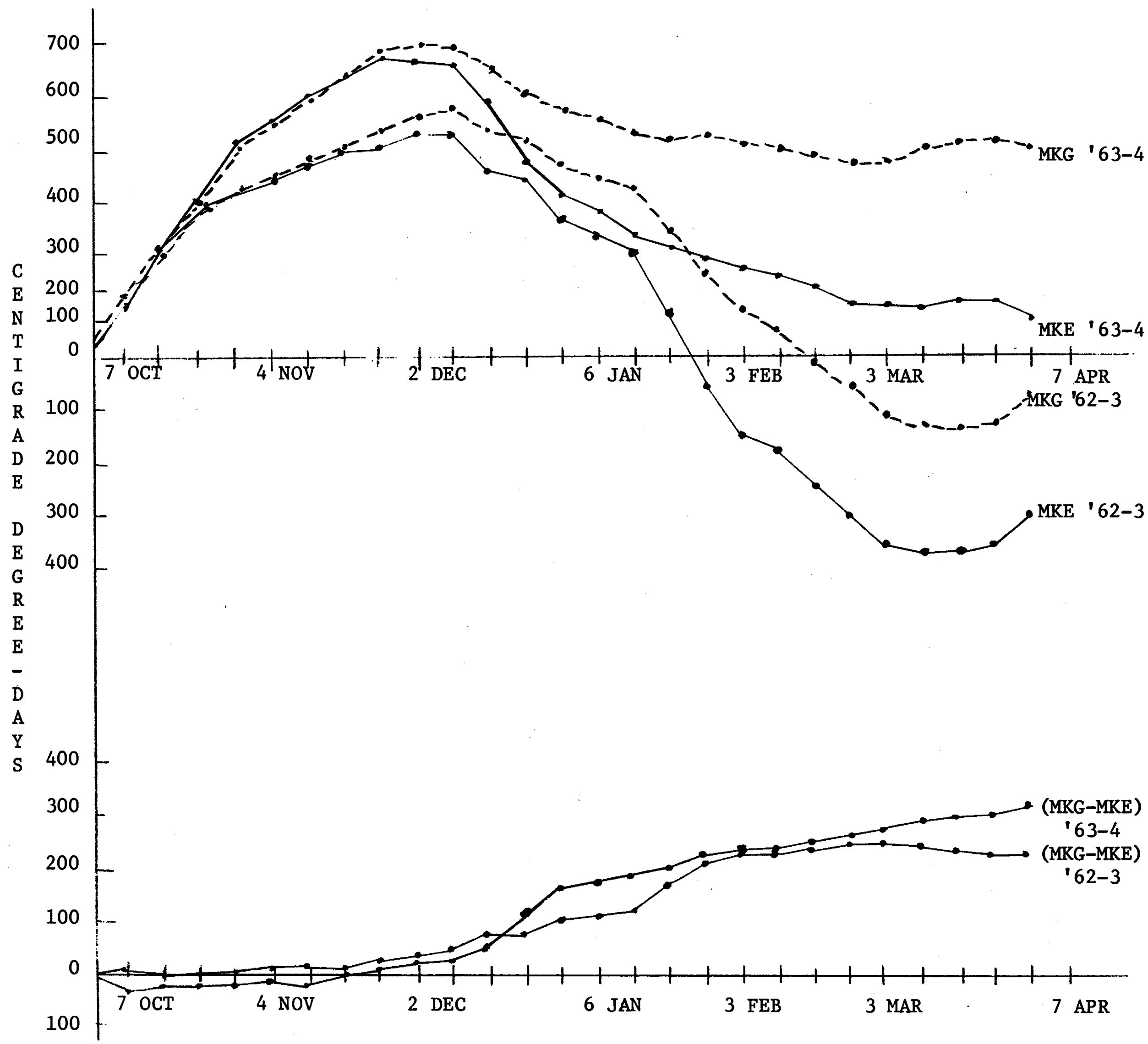

FIG. 8. Cumulative degree days (Centigrade). Air temperature, Milwaukee and Muskegon.

spring minimum for Milwaukee in 1963 was approximately -400 degree days, thus the freezing exposure of the winter season at Milwaukee 1962-63 was 900 degree days. The 1962-63 winter season was a record cold year during which virtually 100% of the lake surface was covered by ice. The following year 1963-64 winter season was a relatively light ice year and a relatively warm winter. The degree day maximum at Milwaukee in the fall of 1963 reached 650 degree days. The 1963-64 winter season was characterized by relatively slow spring warming with the spring minimum being of the order of 100 degree days. The freezing exposure for this winter was the order of 550 degree days. The 1963-64 winter was much milder than that of 1962-63. The corresponding curves for Muskegon are shown in the same figure. The lower set of curves in the same figure represent the difference in cumulative degree days between Muskegon and Milwaukee for the two winter seasons of 1962-63 and 1963-64. In spite of the difference of the severity of the winters, 900 degree days of freezing exposure versus 550 degree days, it was observed that the difference in degree days between Milwaukee and Muskegon was virtually the same for both years. This observation indicated that approximately the same amount of heat was extracted from the lake during both seasons. It appeared, therefore, that the cross-lake difference in the cumulative degree days between pairs of cities approximately the same latitude would give a gross indication of the sensible heat transfer from the lake to the atmosphere.

In order to test the stability of this indication of heat transfer from the lake to the atmosphere, the cumulative degree days were computed for the winter seasons for Milwaukee and Muskegon during the following subsequent seasons of 1964-65, 1965-66, and 1966-67. Table I gives the maximum and minimum values of the cumulative degree days for the winter seasons, with the date of their occurrence for the period of record. The freezing exposures

Table 1. Summary of cumulative degree-day data and freezing exposure for five winter seasons 1962-63 through 1966-67.

MILWAUKEE - MUSKEGON

	Milwaukee					Muskegon				
	Max		Min		Freezing Exposure	Max		Min		Freezing Exposure
1962-1963	479	Dec 9	-387	Mar 10	866	514	Dec 9	-131	Mar 17	645
1963-1964	599	Nov 25	92	Mar 31	507	652	Dec 2	395	Feb 24	257
1964-1965	437	Nov 18	-259	Mar 31	696	455	Nov 25	115	Mar 31	340
1965-1966	478	Dec 16	6	Mar 10	472	512	Dec 16	171	Feb 24	341
1966-1967	389	Nov 25	-134	Mar 17	523	439	Dec 9	124	Mar 24	315

BENTON HARBOR - CHICAGO

	Chicago					Benton Harbor				
	Max		Min		Freezing Exposure	Max		Min		Freezing Exposure
1962-1963	680	Dec 9	121	Mar 24	559	597	Dec 9	41	Mar 3	556
1963-1964	803	Dec 2	524	Mar 3	279	714	Dec 9	522	Feb 24	192
1964-1965	612	Nov 18	268	Mar 31	344	569	Nov 18	314	Mar 31	255
1965-1966	707	Jan 6	419	Feb 24	288	726	Jan 6	519	Feb 24	207
1966-1967	521	Nov 25	206	Mar 10	315	378	Dec 9	108	Mar 10	270

MANISTEE - TWO RIVERS

	Manistee					Two Rivers				
	Max		Min		Freezing Exposure	Max		Min		Freezing Exposure
1962-1963	521	Dec 9	-194	Mar 24	615	464	Dec 9	-376	Mar 24	840
1963-1964	638	Dec 2	292	Mar 31	346	578	Nov 25	166	Mar 31	412
1964-1965	512	Nov 18	67	Mar 31	445	411	Nov 18	-256	Mar 31	667
1965-1966	497	Dec 16	191	Feb 24	306	428	Dec 16	- 24	Mar 10	452
1966-1967	422	Nov 25	67	Mar 24	355	355	Nov 25	-169	Mar 24	524

for these five winter seasons are also indicated in the table. Figure 9 shows the cumulative degree day difference between Muskegon and Milwaukee for each of the five seasons.

Corresponding calculations were carried out for two additional station pairs, one at the south end and the other at the north end of the lake. The station pairs selected for the south end of the lake were Chicago and Benton Harbor; at the north end Manistee and Two Rivers. The cross-lake differences of the degree days between the station pairs are shown in Figures 10 and 11.

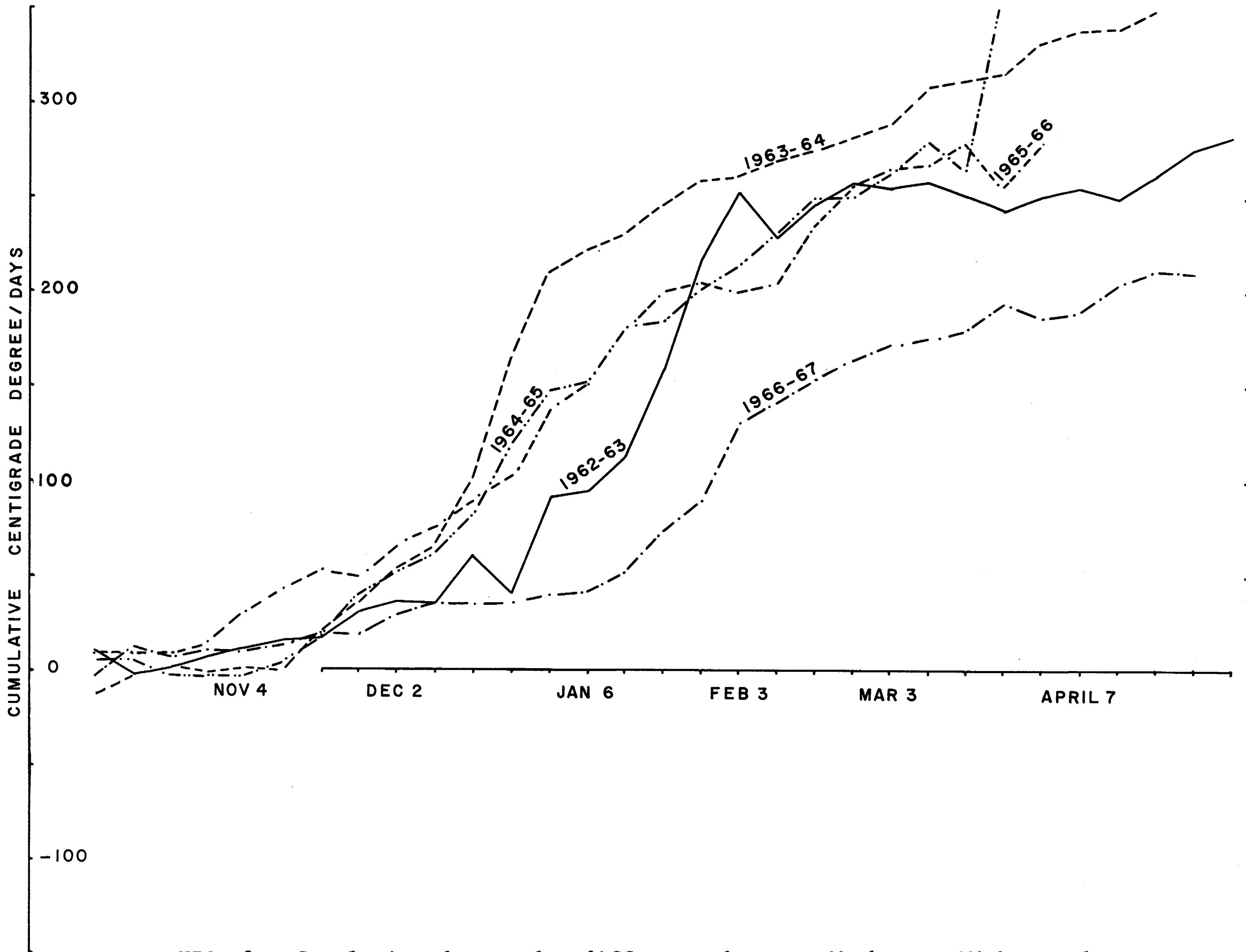

FIG. 9. Cumulative degree day difference between Muskegon, Mich., and Milwaukee, Wis.

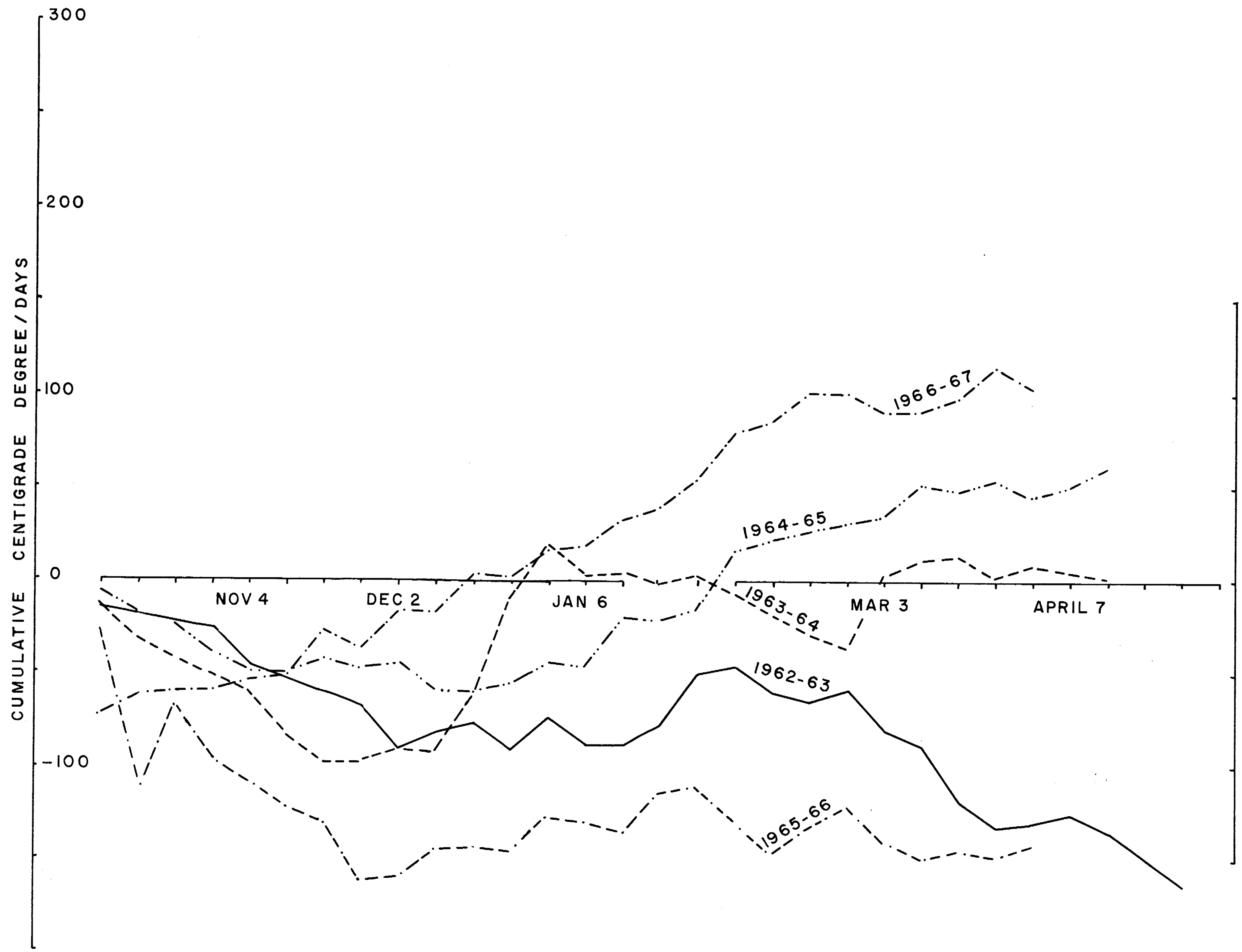

FIG. 10. Cumulative degree day difference between Benton Harbor, Mich., and Chicago, Ill.

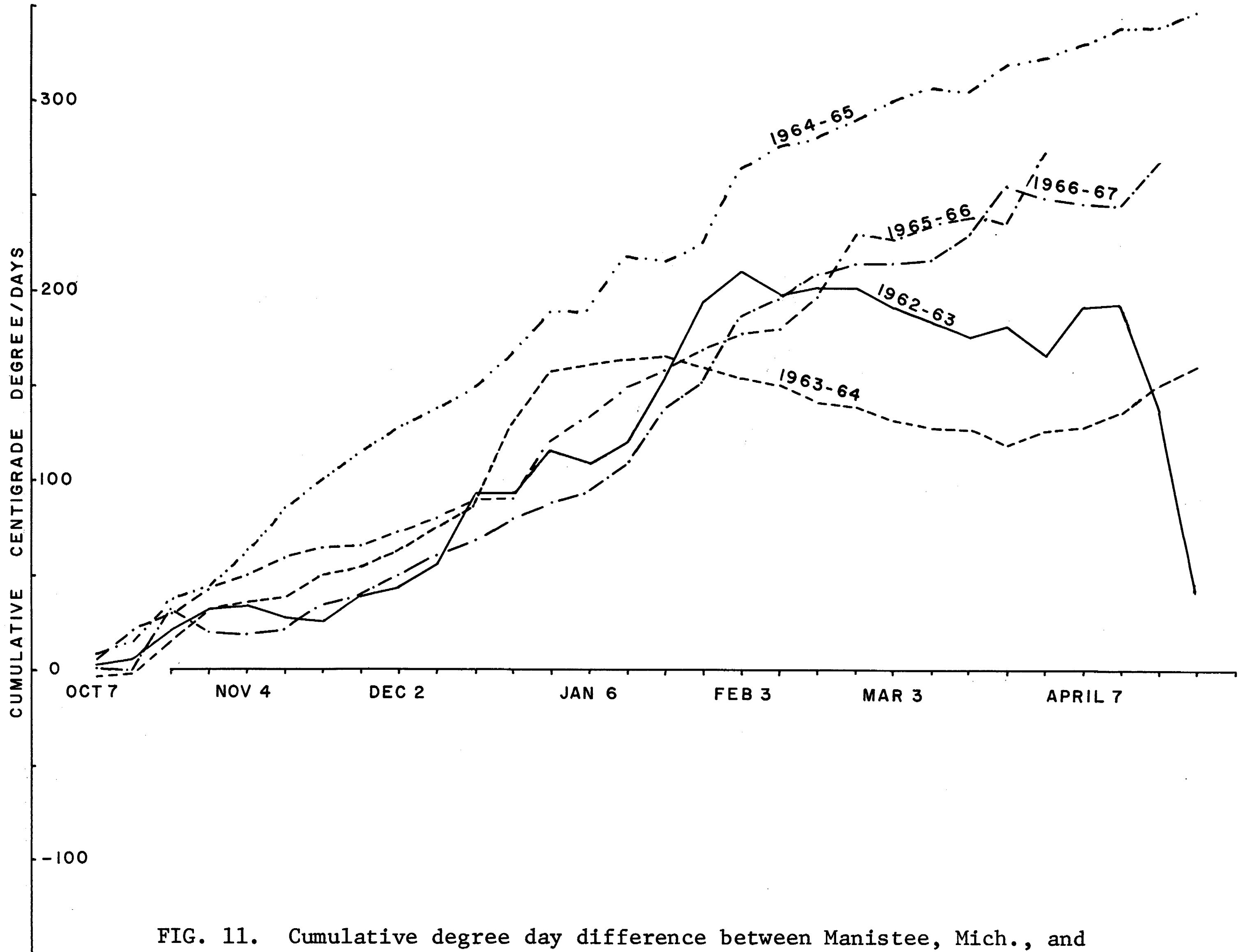

FIG. 11. Cumulative degree day difference between Manistee, Mich., and Two Rivers, Wis.

WORK IN PROGRESS

There are two complimentary programs currently in progress within the Great Lakes Research Division. The first program is that of reducing all of the early bathythermograph data and punching the data onto IBM cards for computer processing. The first step of the analysis program has been to compile an average temperature of Lake Michigan by 1° latitude-longitude squares by 10-meter depth interval by months for the years 1963 through 1966. Data from 1962 back through 1955 will be analyzed in the near future. The early 1967 data are now being worked up. These bathythermograph data pertain generally to the summer period of the year. These data, when correlated with the air temperature measurements and the early winter water temperature observations made by the Coast Guard Cutter WOODBINE, will help to give a measure of the integrating effect of the water mass in Lake Michigan. It has been shown by Ayers (1965) that the temperature, i.e., heat budget trends for the water mass in Lake Michigan, can be projected for a 4-year basis from climatological data. The bathythermograph heat analysis will help to more accurately document the effects of the heat capacity of the water mass upon the temperature structure at any given period of any given year.

The Lake Michigan winter temperature data as obtained from the U.S. Public Health Service Great Lakes-Illinois River Basins Project buoy system for the years 1962-1963 are being tabulated and will be published as a special data report giving the 90-minute interval temperature readings for all of the recording stations in Lake Michigan for these two years. There are 14 recording thermograph records available for Lake Huron during the year 1965 that have been reduced, and these data will also be included in the temperature report.

Airborne infrared surface temperature measurements have been carried out during the early fall of 1966 by the U.S. Naval Oceanographic Office ASWEP Constellation EL COYOTE. It is anticipated that a repeat of this experiment will be carried out in October of 1967. These two sequences of field operations will contribute to our understanding of the surface currents and surface temperature distributions of Lake Michigan, and, when used in conjunction with the bathythermograph and air temperature climatological data, will contribute to our understanding of the heat budget of Lake Michigan.

The integrating radiometers are undergoing further testing in the laboratory this summer and will be installed at six Coast Guard stations around the basin of Lake Michigan for the 1967-68 winter season. The indicating thermistor temperature bridge is being recalibrated and will be installed on board the U.S. Coast Guard Cutter WOODBINE for use during the remainder of the summer of 1967 and through the winter of 1968. A second unit has been constructed and will be offered to the SUNDEW in order that accurate surface temperature data may be obtained from the northern end of Lake Michigan.

It is expected that by the termination of the project, 1 June 1968, five continuous years of air temperature climatological data and bathythermogrametric water temperature measurements, and one year of solar radiation input data will contribute to a more detailed analysis of the heat budget of Lake Michigan and will provide an adequate basis for evaluation of ice prediction techniques.

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